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Aspects of Self-Organisation in Cellular Networks

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Abstract

This paper discusses some aspects of self-organisation in future cellular communications. In particular the effect sub-optimal base station positioning has on the overall interference level in the network. It is shown that the interference level increases with basestation positioning error resulting in unacceptable dropping probability.

With the incorporation of a simple power control algorithm, the network's sensitivity to error in base station positioning is reduced and an improvement in the performance is achieved. The results also show that a considerable tighter re-use pattern can be used in order to accommodate more users in the same spectrum.

I. Introduction

Radio wave propagation modelling has been one of the main activities that researchers in mobile communication have been involved in. Both statistical and deterministic models have been developed and are providing the basis on which cellular networks are planned today. In particular base station location and frequency allocation. Whilst deterministic models such as ray tracing can provide accurate coverage predictions, they are computationally complex and require accurate map databases for the area of interest [1]. Statistical models are simple to use but do not provide specific information about a particular area. The network planning process aims to achieve network coverage and capacity while minimising the infrastructure required and maximising the resource utilisation, hence generating a high turnover on invested capital. Due to the possible unavailability of ideal Base Station (BS) sites, changes in the radio environment or other factors, the planning process may have to be done repeatedly, considering the new parameters.

As an alternative approach to accurate planning, the concept of intelligent networks or self-organising networks has been proposed. The network performance sensitivity to planning parameters is reduced by intelligence incorporated in the system. There are various issues associated with self-organisation, one being channel allocation. Dynamic channel allocation (DCA) algorithms, which are suitable for this kind of network, has been studied extensively in the literature [2].

However, the issue of base station location has received less attention. In this paper, the network performance sensitivity to sub-optimal BS locations will be discussed in detail. In particular how a simple power control algorithm can be employed to combat the increased interference levels. The research is motivated by ETSI's selection criteria [3] for the next generation wireless networks which includes whether:

- Multiple unsynchronised systems can successfully coexist in the same environment
- Base stations can be installed in an uncoordinated manner
- No frequency planning is required

As an example of a fully operational radio network, which uses the idea of self-organisation, section II will discuss how the PHS system works. Section III explains the power control simulation procedure and the power control algorithm. Section IV explains the simulation procedure. Section V presents the simulation results. Finally, in section VI a number of conclusions are drawn from this study.

II. Self organisation in PHS

The Japanese Personal Handy-Phone System (PHS) technology is possibly the best example of self-organisation in mobile communications in practice [4]. The main aim for PHS is to provide wireless multimedia communications, terminal mobility, complete two-way communications and an alternative access method to the fixed network. The main difference from a traditional cellular communications network is in the deployment characteristics. The system consists of thousands of very small base stations, called Cell Stations (CS) in PHS terminology, which are distributed without any frequency planning. The CS are connected directly to the existing public telephone network, removing the need for expensive dedicated switching and location management in the cellular network. All the intelligence is provided through the PSTN. Obviously, this fashion of deployment requires that there are substantial spare capacity in the PSTN which can be dedicated for this usage. In Tokyo there are 30 000 CS placed on top of public phones. All the public telephones have an additional ISDN line, which is used by the CS. Each CS (low power version) has a volume of approximately 5 litres in addition to feeding cable and a small omni directional antenna. One CS can only support 1 carrier

providing an up and down link for a total of 3 calls in addition to a Broadcast Control Channel (BCCH). The coverage area for each CS is small with a radius of 100m to 500m, thus providing a substantial amount of capacity. However, if more capacity is required then more CSs can be placed in the same cell. Only the original CS needs to provide a BCCH, so any additional CSs can support 4 calls. No reconfiguration of the network is required if more CSs are installed since PHS employs Dynamic Channel Allocation (DCA) rather than Fixed Channel Allocation (FCA).

III. Channel assignment

The work accomplished by Nettleton and Schloemer [5][6][7] in the early nineties identified some of the problems associated with non-uniform traffic, both in time and space. They applied various DCA techniques in order to achieve self-organisation. The simulation tool that was developed for that research is very similar to what has been designed for this work. Results from that work clearly shows that a self organising DCA technique based on a local measurement of C/I at both the Mobile Station (MS) and BS, outperforms FCA with 300% increase in capacity. Although the amount of channels available in the FCA and DCA scheme is the same, the number of radios in the network were 2.5 times higher in the DCA case. This is clearly a contributing factor to the substantial increase in capacity.

IV. The Network simulation

A new real time simulation tool has been developed to investigate various aspects of the network performance. The tool is very flexible and can provide results for a variety of issues. The current simulation is set up with 37 base stations (4 tiers of cells), but only data from the inner 3 tiers are analysed so that the edge effect is avoided. Refer to Table 1 for more

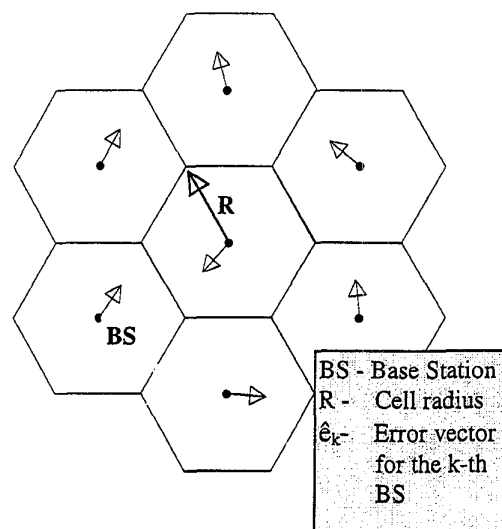


Figure 1: Sub optimal positioning of base stations

information about the set-up.

The analysis presented here investigates how the positioning of the BS effects the overall network performance. Figure 1 shows the network where the base stations are moved to sub optimal positions. In order to achieve a satisfactory network loading, the initial blocking probability is rather high (5%). The network aspects are otherwise as for a GSM network, using theoretical values for S/N and C/I as given in the GSM specification [8]. A re-use distance of 7 is used without sectorisation, which is less than the usual 12 employed in GSM macrocellular networks. This causes a rather high dropping probability, but the re-use factor is chosen to clearly show how much improvement can be achieved with power control. The blocking probability is ignored in the analysis since the traffic level is the same for all

Table 1: Simulation parameters (GSM type network)

Simulation type	Real time simulation with live downlink only
Network size	37 base stations
Channels	3 carriers per BS, 8 channels per carrier
Re-use distance	7 (total of 168 channels)
Call characteristics	voice only, birth-death process, no movement
Call duration	120 seconds with 15 second standard deviation (Gaussian distributed)[9]
Call arrival	6 per second - uniformly distributed (chosen to give high network loading)
Propagation model	Dual slope with break point at 100 meters, (d^{-2} , d^{-4}), log-normal shadowing of 8 dB
Cell radius	600 meters
BS properties	30 dBm max. power, 8dBi antenna gain, no sectorisation
BS power control	Threshold -85 dBm min power experienced by the user
User properties	0 dB antenna gain, 9dB C/I required, -105 dBm min signal strength

simulation runs.

There are 4 parameters that are currently monitored during the simulation.

- Blocking probability - Users are denied access due to the lack of available channels in the base station.
- Blocking interference probability - Users are allocated a channel but the C/I is too poor so the call is immediately lost
- Dropping probability - During a call the C/I becomes unacceptable so the user is dropped
- Link quality - The C/I level for each call is monitored

IV.A The power control algorithm

The power control algorithm is very simple. The threshold is set to -85 dBm, accounting for a 20 dB fade margin from the S/N limit of -105 dBm. Whenever a user makes a connection, the BS will reduce its power so that the MS only will receive a signal of -85 dBm. All users in a cell will therefore experience this signal level, unless severe shadowing causes the path loss greater than what the BS transmit power can compensate for. However, the BS transmit power is set such that the signal strength should be approximately -80 dBm at the cell boundary. Only a fraction of the users will therefore experience power levels below -85 dBm. As more users enter the network, the interference level rises. If the C/I criterion for a single user falls below the threshold, the transmit power will be increased in steps of 1dB. This is repeated until the C/I criterion is met or maximum transmit power is reached. The user is dropped if this procedure fails to produce a satisfactory C/I.

V. Simulation Results

The first set of results look at the performance of the network with a propagation model of d^{-2} up until 100 meters and d^{-4} after that, user arrival rate of 6 users pr second and a FCA scheme. The performance in terms of blocking and dropping probability

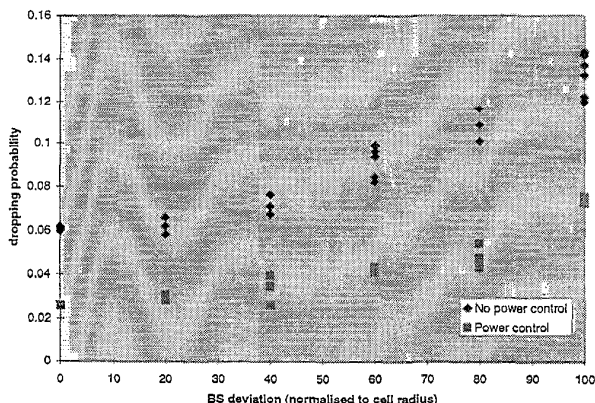


Figure 2: Performance with sub-optimal BS positioning

is recorded after every simulation run. A set of trials were done with increasing positioning deviation of the base stations from their optimal position in a hexagonal network. The deviation is measured in % of cell radius. In this case the cell radius is approximately 600 meters. Several samples are done for 0, 20, 40, 60, 80 and 100% deviation from optimum position. All BS's are positioned at this distance from its original location but with a random direction. Figure 2 shows some typical simulation results from several tries both with and without power control. The results clearly show the benefits of power control. Even in a hexagonal network with no error, the power control algorithm provides a 66% improvement in dropping probability. As the error increases, the dropping probability quickly becomes unacceptable without power control. With power control the dropping probability does not exceed 4% even with a 60% deviation in the BS placement. The deviation from the mean blocking probability increases with BS deviation, making performance predictions more uncertain.

V.A The accuracy of the power control

Power control accuracy has proved to be one of the key issues for successfully implementing air interface techniques such as conventional CDMA [10]. Whilst power control is crucial in CDMA to achieve a reasonable performance, the power control investigation undertaken here is merely to look at the effect it

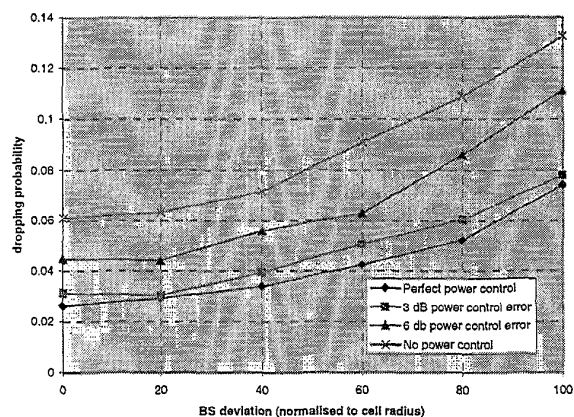


Figure 3: Network performance with power control error

has on the dropping probability (C/I performance) in the network

In Figure 3 the network performance is shown as a function of the mean dropping probability for 4 simulation runs with increasing power control error. With 3 dB error, the performance is degraded by approximately 10 - 25% over the entire range. This level of power control accuracy should be achievable in a practical system. Although not perfect, it still provides a substantial improvement in the dropping probability compared with no power control. With 6 dB error the

degradation is substantial, but still provides a performance improvement.

V.B The impact of the propagation model

Some additional simulation runs were done with the propagation model changed to d^{-2} and $d^{-3.5}$ after a break point of 100 meters. The value of n in d^{-n} has been measured in various cities around the world. A substantial variation is reported, but values between $n = -3$ and -4 are widely used as an approximation [11].

In order to maintain the same cell radius, the maximum base station transmit power was reduced to 16 dBm. Although less

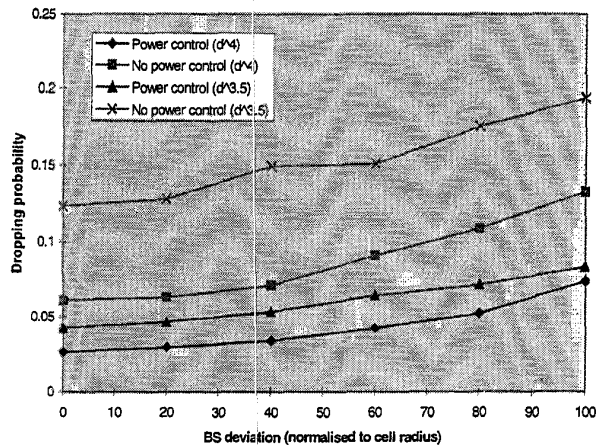


Figure 4: The propagation models influence on the network performance

transmit power is required to cover the cell, the user will experience the same power level at the edge of the cell regardless of the propagation model. However, with a higher path loss exponent, interference will be reduced and hence a better C/I ratio is achieved. Figure 4 shows that without power control in a network where the path loss exponent is smaller and transmit power is reduced appropriately, the interference level is higher for a lower path loss exponent. With power control, the relative improvement is greater in the $d^{-3.5}$ case than with d^{-4} . However, the performance is better with a higher path loss exponent. This shows that power control is more important when there is less urban shielding due to the higher interference levels.

V.C Call interference level

During the simulation the C/I ratio experienced by each user was logged at the start of the call. Although the user is likely to experience a variation in the C/I during the call, the average remains the same for the duration of the simulation. The initial C/I level therefore shows a typical snapshot of the interference level. Figure 5 shows the C/I for the users when no power control is used. As the randomness in the network increases, the number of calls not accepted onto the network due to

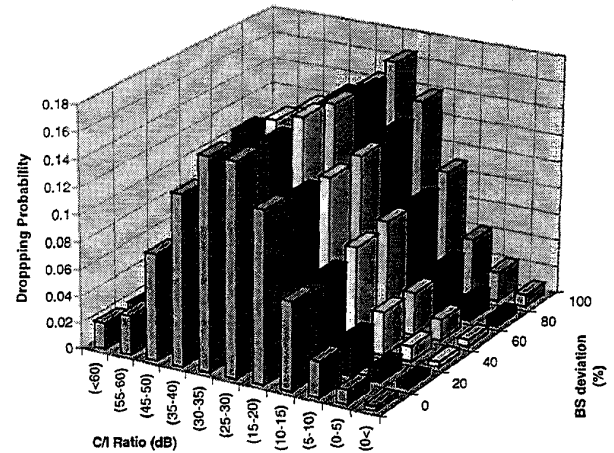


Figure 5 C/I ratio at start of call - No power control

interference rise. On the other hand, a number of users experience an unnecessarily high C/I ratio, which suggests that spectrum is wasted. (The graph does not show the users that are dropped during the call.) With the use of DCA based on distributed interference measurements the C/I level will be lowered and hence more users could be supported in the network.

When the power control algorithm is applied, the initial

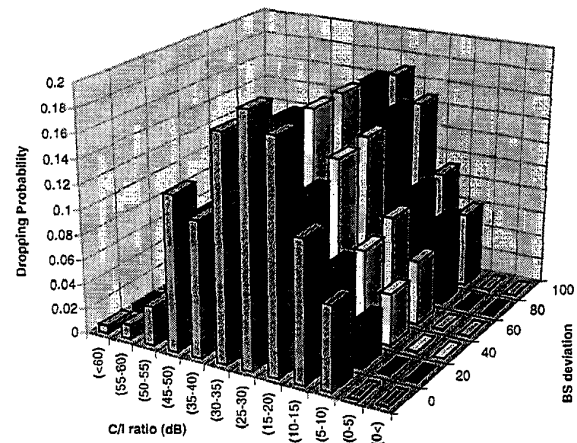


Figure 6 C/I ratio at start of call - With power control

dropping probability decreases substantially since all users have reduced their power. Marginal users can then increase their power in order to combat interference and hence avoid being dropped. Figure 6 clearly shows the number of users that experience C/I lower than 10 dB is significantly reduced. This explains the improvement in dropping probability shown in

Section V. In addition, the number of users that experience a higher C/I ratio than 50 dB is reduced. The results also show that the network could employ a tighter re-use factor and therefore support more users with the same number of channels. Ideally all users should experience a C/I in the 10 - 15 dB region for maximum spectrum utilisation. These results are in line with what Nettleton reported in [6].

VI. Conclusion

The results shown in this paper were produced for a very simple cellular configuration with constant traffic and no moving users. Network performance as a function of BS positioning error has been investigated in some detail. The results clearly show that for a GSM type system that originally can not be deployed with a re-use of 7 (no sectorisation) due to an unsatisfactory dropping probability, can function if a simple power control scheme is applied.

As the randomness in the network is increased, the performance is severely degraded. This is due to there being active interfering connections too close to each other. The blocking probability increases due to the cells different coverage areas. Some cells will therefore cover bigger areas but with no added capacity, resulting in increased blocking. This can be combated with dynamic cell sizes where the user first tries to connect to the nearest base station. If this fails, it successively tries to connect to the next strongest BS. This is not discussed any further in this paper but will be the subject of future work.

With power control, the results clearly show that a definitive improvement in the performance can be achieved even with a quite severely distorted network, where 50% error only gives 4% dropping. This result would improve if sectorisation were applied to the network. In the case of a microcellular network, the antenna is most likely to be mounted on a wall, effectively providing 180° interference protection (2 sectors).

These preliminary results have shown that the use of power control substantially reduces the network's sensitivity to base station positioning in a network. For obvious reasons, FCA is not the best technique to apply in a self organisation scheme. If a DCA scheme had been utilised, the dropping probability would have decreased substantially due to the unnecessary high C/I experienced by some users. In many cases some channels could be re-used at a much closer distance due to urban shielding etc. This would bring the C/I down into the wanted region of 10-15 dB depending on the threshold in the system. Again this will free capacity for marginal users and will prevent some calls from being dropped.

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